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Yokoyama

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(54) **BIT EXCHANGE METHOD AND BIT EXCHANGE DEVICE FOR SHIELD TUNNELING MACHINE**

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B23Q 3/155 (2006.01)

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(58) **Field of Classification Search**
CPC E21D 9/104
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,421,422	A *	6/1995	Crane	E21D 9/104 175/363
6,347,838	B1 *	2/2002	Mukaidani	E21D 9/104 299/55
8,523,288	B2	9/2013	Hanaoka et al.	299/56
2013/0045055	A1 *	2/2013	Derycke	E21D 9/104 405/138

FOREIGN PATENT DOCUMENTS

JP	2000-096987	4/2000	E21D 9/08
JP	2001-027097	1/2001	E21D 9/08

(Continued)

OTHER PUBLICATIONS

International Search Report for International Application No. PCT/JP2012/063419, Aug. 28, 2012.

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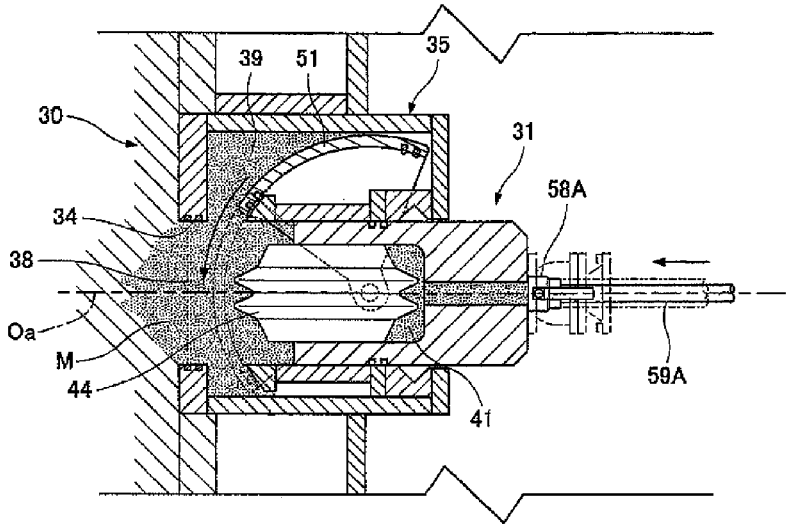
(57) **ABSTRACT**

Sealing in the sliding gap of a rotating valve is improved to smoothly rotate the rotating valve during replacement of a roller bit. A valve housing portion is formed behind a bit housing portion having an opening at the front of a main cutter spoke. A rotating valve is rotationally disposed as a rotating body in the valve housing portion. A bit case containing the roller bit is moved into the bit housing portion so as to protrude from a removable passage of the rotating valve, and then the bit case is fixed by a cotter member to support a drilling reaction force. Thus, the sliding gap of the rotating valve is disposed in the bit housing portion and the valve housing portion and is covered with the bit case.

6 Claims, 9 Drawing Sheets



(56) **References Cited**

FOREIGN PATENT DOCUMENTS

JP	2003-253989	9/2003	..... E21D 9/08
JP	2004-211477	7/2004	..... E21D 9/087
JP	3139749	2/2008	..... B41J 25/308
JP	2008-063801	3/2008	..... E21D 9/087
JP	4163965	8/2008	..... E21D 9/087
JP	2011-6932 A	1/2011	..... E21D 9/087
JP	4722220	7/2011	..... E21D 9/087
JP	2012-041781	3/2012	..... E21D 9/087

* cited by examiner

FIG. 1

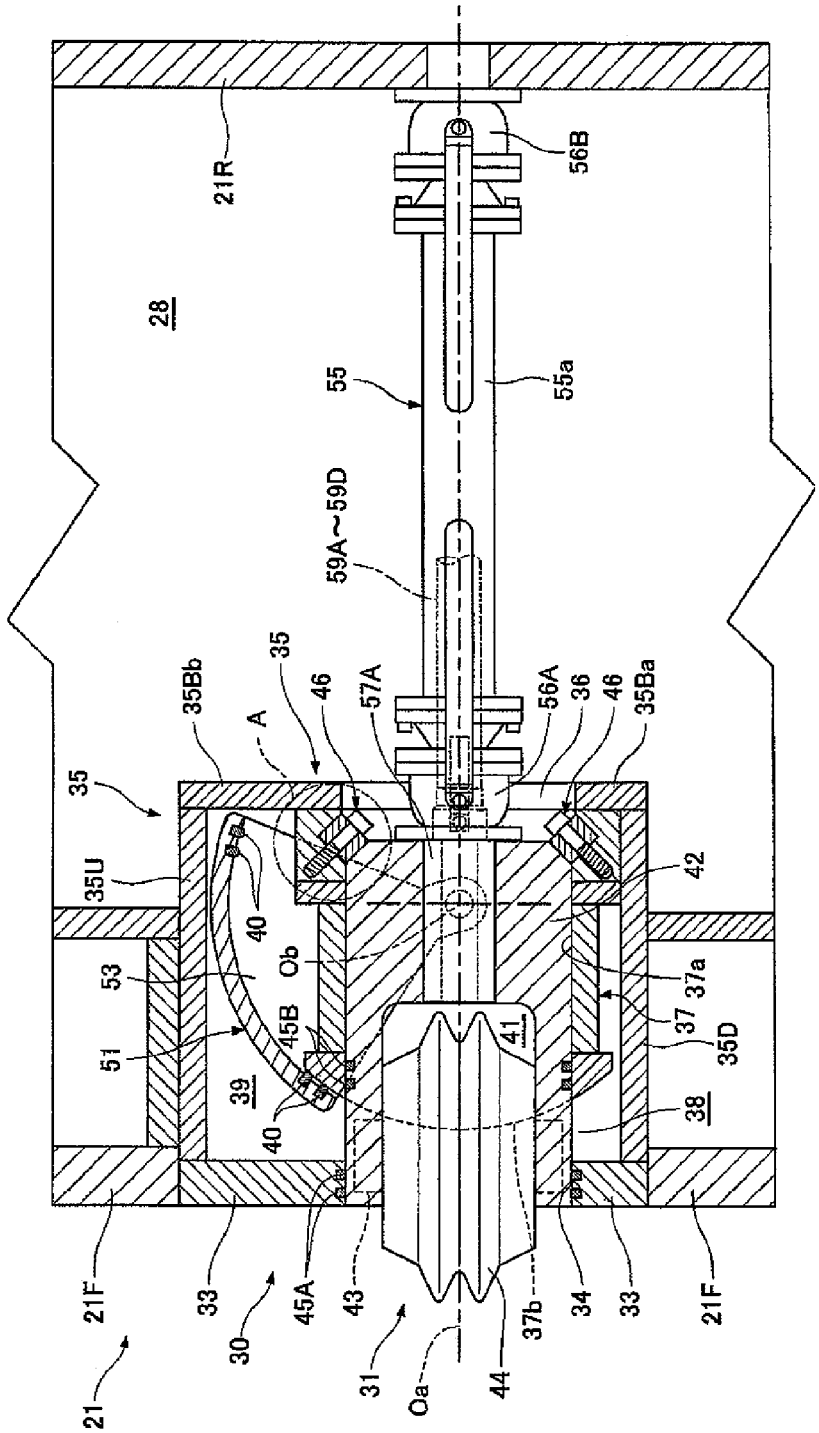

21R
56B
28
55
55a
59A~59D
35Bb
A
35
46
57A
56A
36
46
35Ba
35
35U
42
40
Ob
53
37a
37
35D
51
45B
41
39
40
38
21F
33
45A
43
37b
34
33
21F
21
30
31
Oa
44

FIG. 2

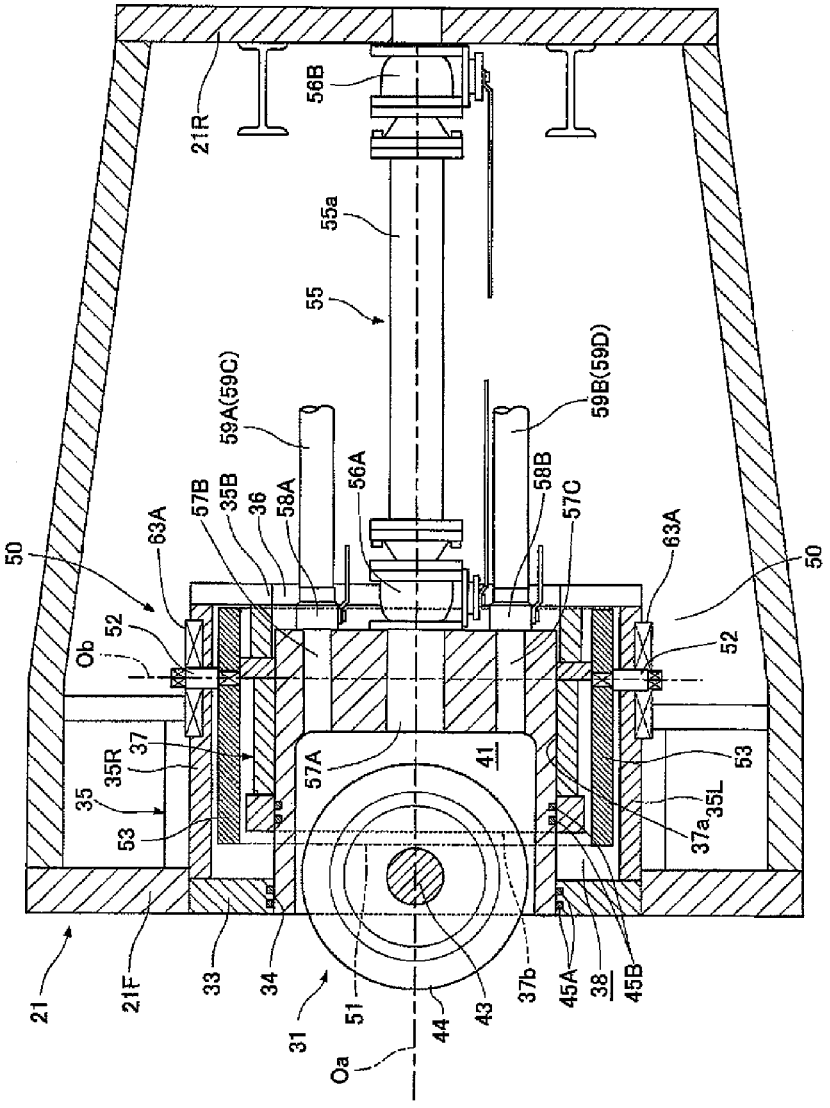
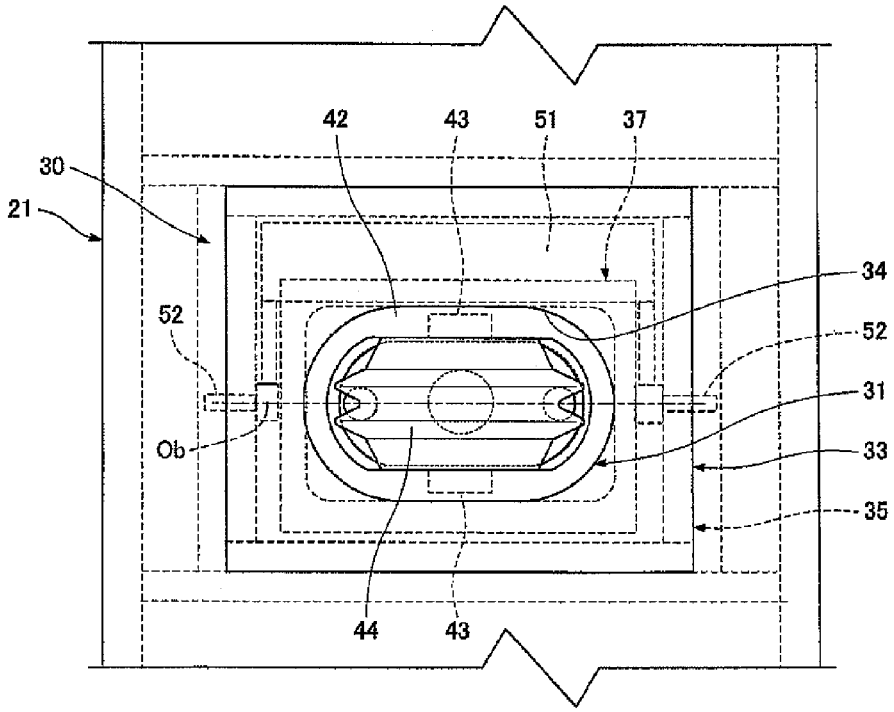

21R
56B
55a
55
59A(59C)
59B(59D)
56A
58B
57C
57B
35B
36
58A
63A
50
52
Ob
37
35R
35
53
57A
41
35L
37a
21
21F
33
34
31
51
44
43
37b
45A
38
45B
Oa

FIG. 3A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30
21
34
52
52
31
Ob
33
35
44
43

FIG. 3B

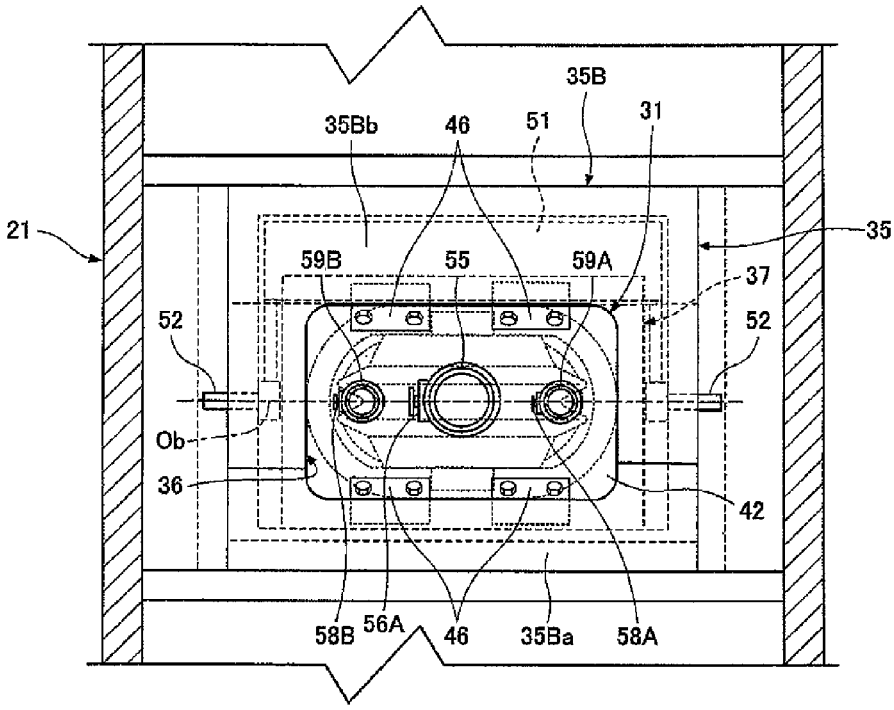
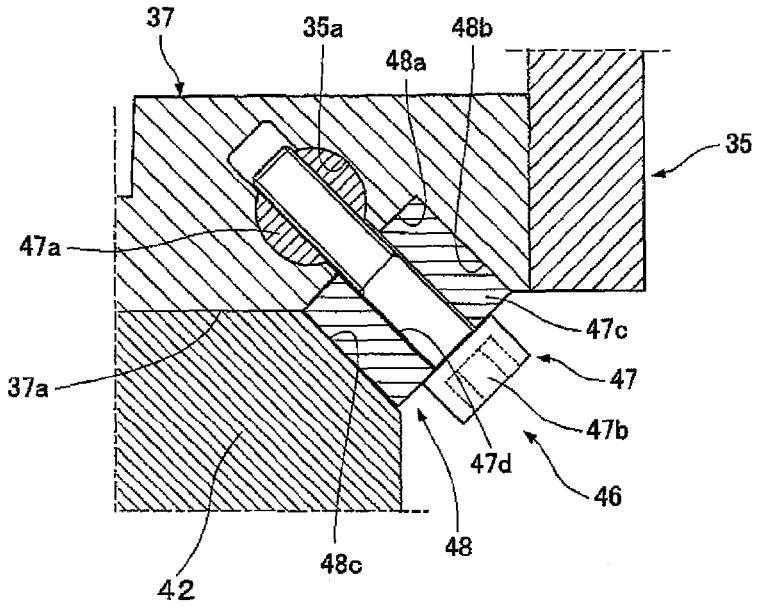

35B
35Bb
46
51
31
21
35
59B
55
59A
37
52
52
Ob
36
42
58B
56A
46
35Ba
58A

FIG. 4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35a
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48a
35
47a
47c
47
37a
47b
47d
46
48
48c
42

FIG. 5

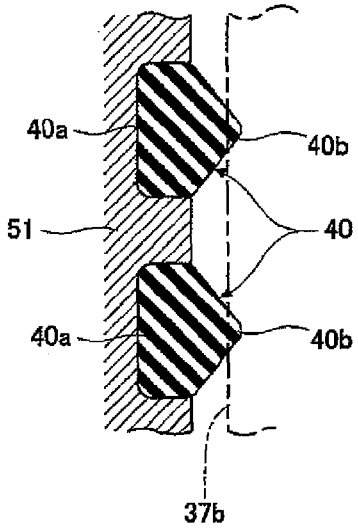

40a
40b
51
40
40a
40b
37b

FIG. 6

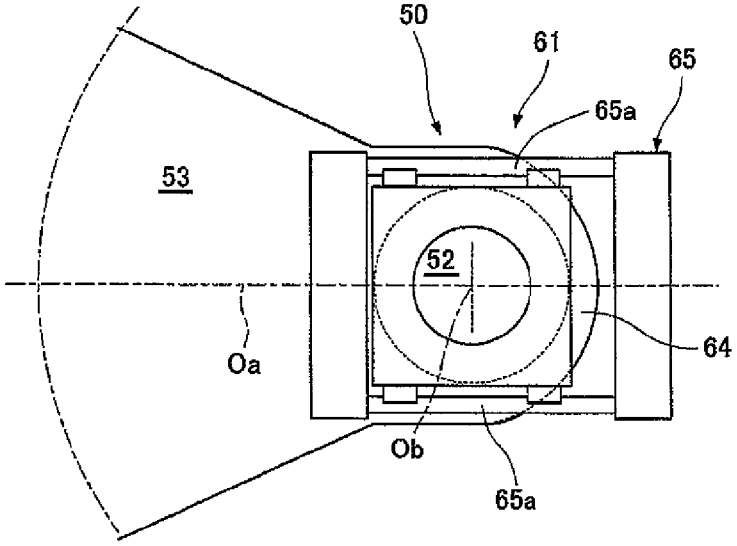

50
61
65
65a
53
52
64
Oa
Ob
65a

FIG. 7

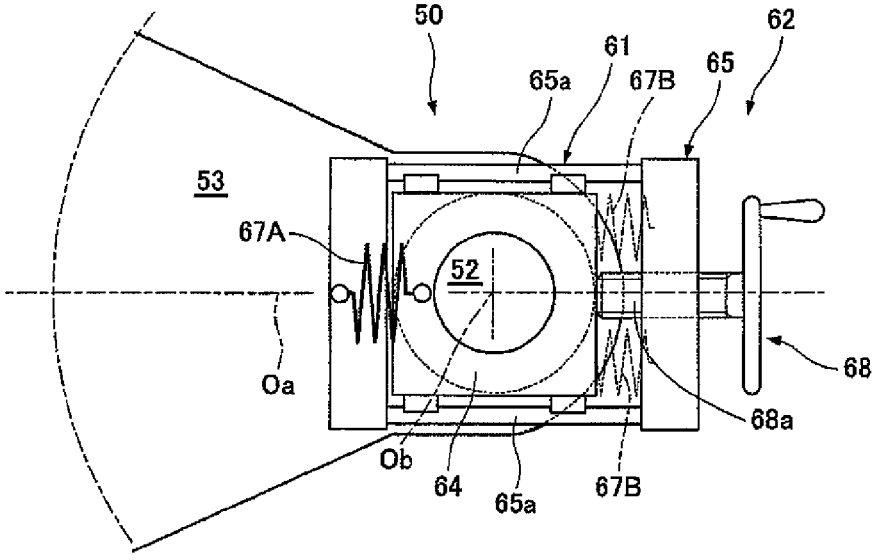

50
62
61
65a
67B
65
53
67A
52
68
Oa
68a
Ob
64
65a
67B

FIG. 8A

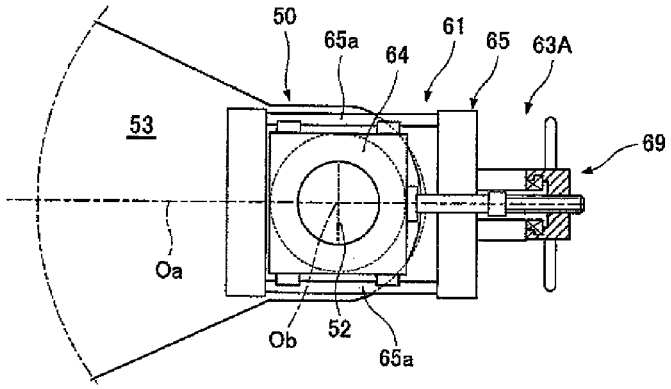


FIG. 8B

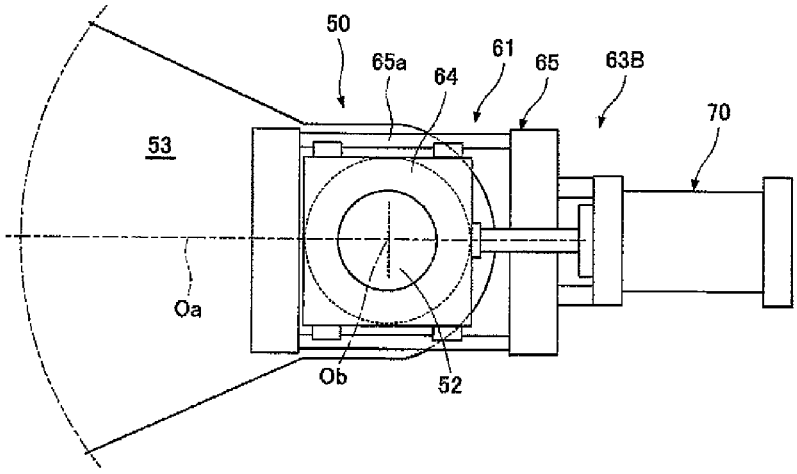


FIG. 8C

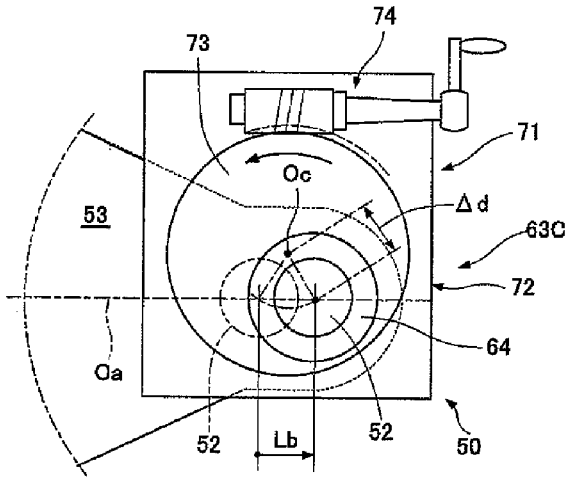


FIG. 9

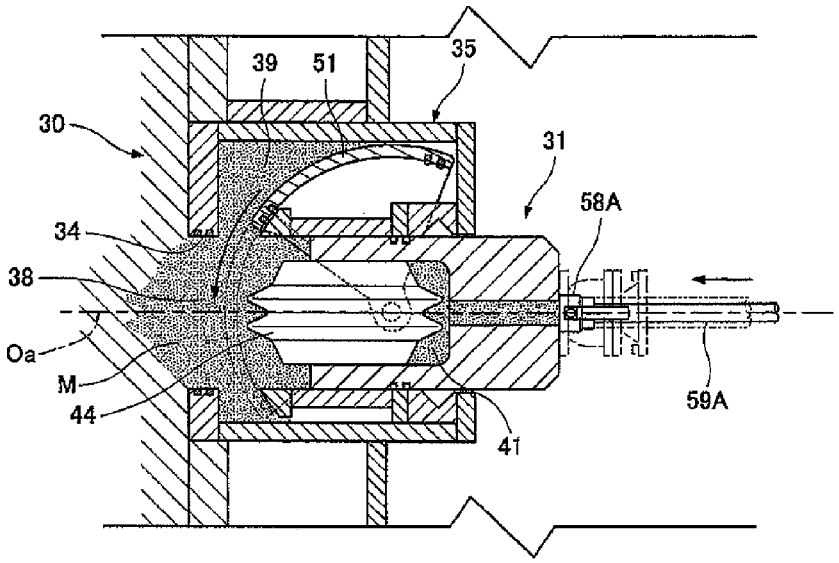

39
51
35
30
31
58A
34
38
Oa
M
44
41
59A

FIG. 10

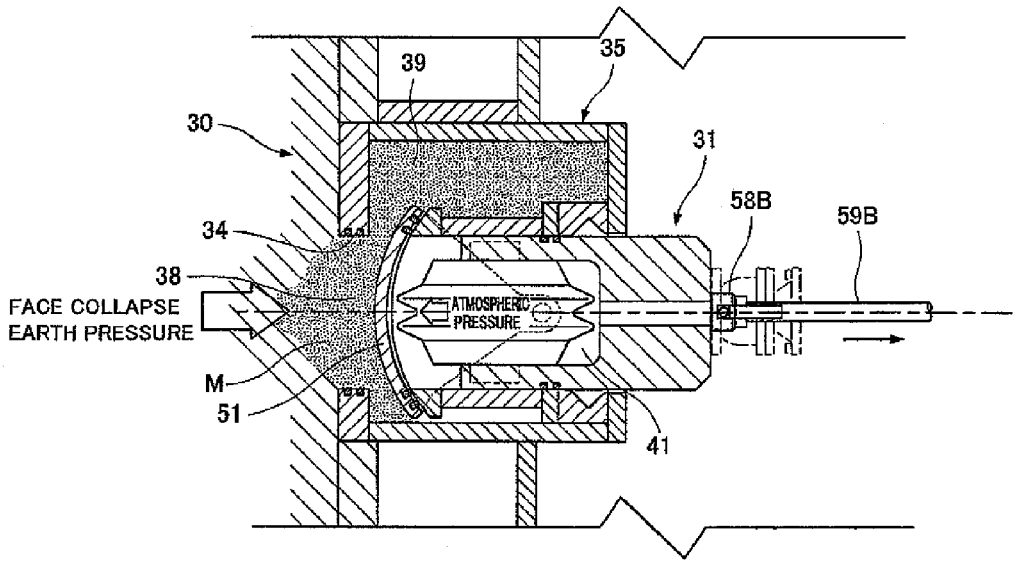

39
35
30
31
58B
59B
34
38
FACE COLLAPSE
EARTH PRESSURE
ATMOSPHERIC
PRESSURE
M
51
41

FIG. 11

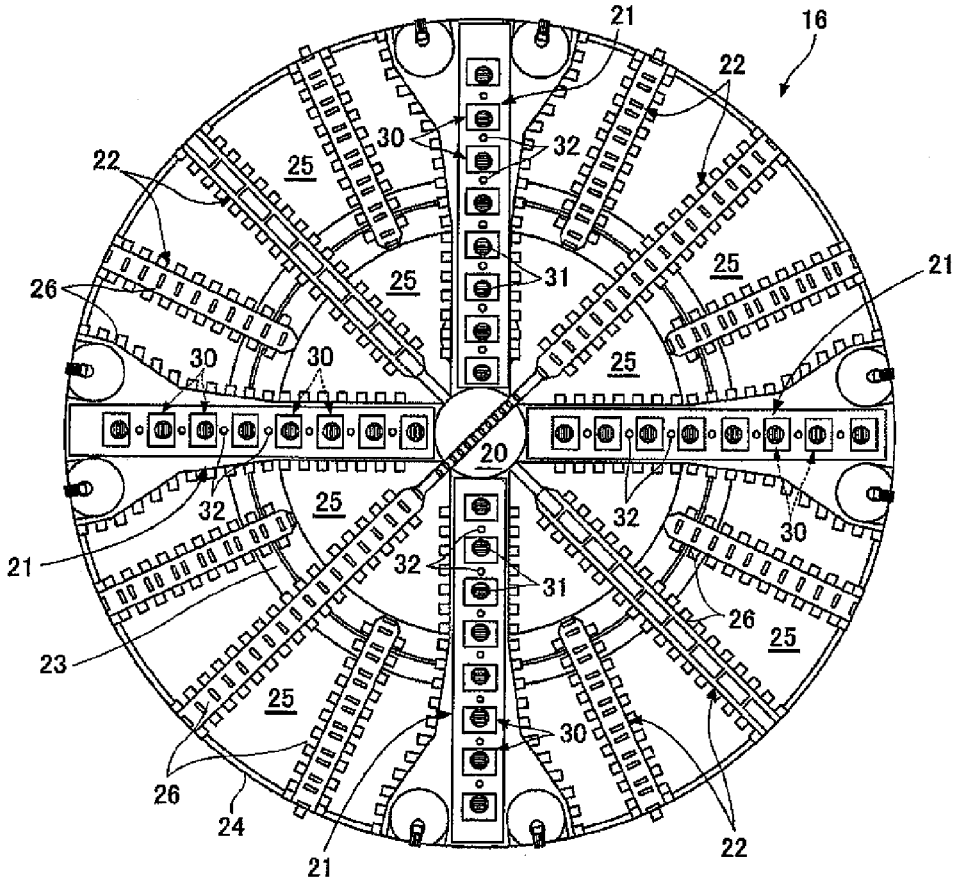
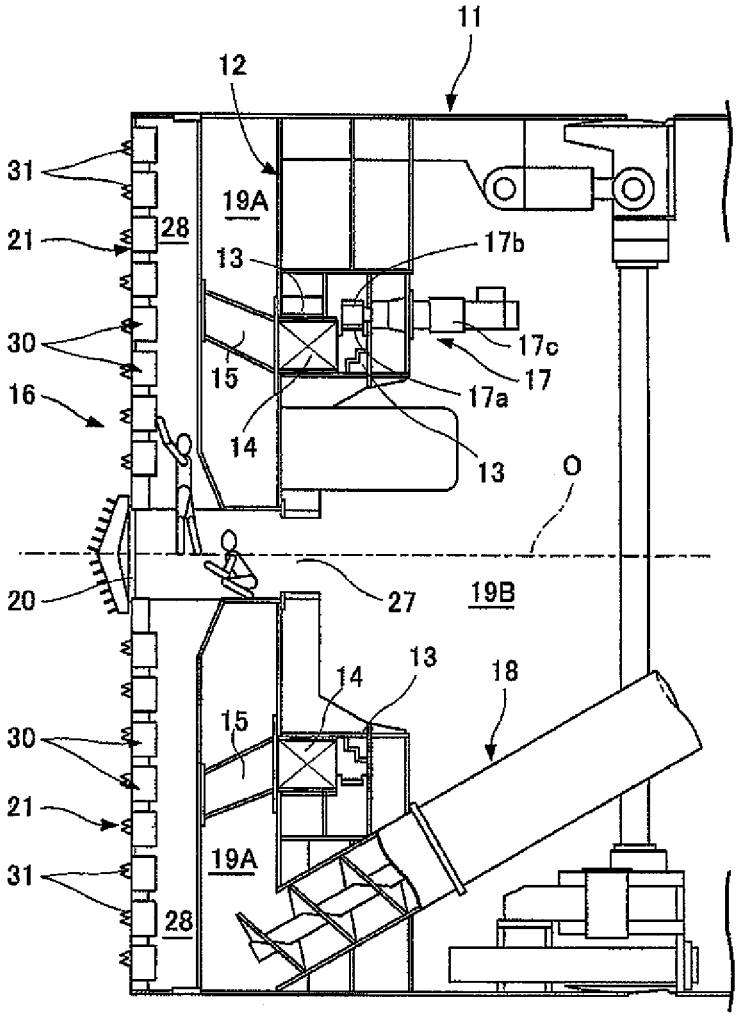


FIG. 12


11
12
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19A
28
21
13
17b
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17c
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17
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17a
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13
O
20
27
19B
14
13
18
30
15
21
19A
31
28

BIT EXCHANGE METHOD AND BIT EXCHANGE DEVICE FOR SHIELD TUNNELING MACHINE

FIELD OF THE INVENTION

The present invention relates to a bit exchange method and a bit exchange device which allow drill bits worn by drilling, e.g., a cutter bit and a roller bit to be exchanged during drilling from a working space kept at an atmospheric pressure in a cutter head in an earth-pressure shield tunneling machine that tunnels natural ground to form a tunnel while keeping a face collapse earth pressure.

BACKGROUND OF THE INVENTION

For example, a bit exchange device for exchanging a roller bit from a working space formed in a cutter head is disclosed in Japanese Patent No. 3139749 and Japanese Patent No. 4163965. The two bit exchange devices each have a rotating body with an opening at the front of cutter spokes. The roller bit is disposed in the opening of the rotating body. In replacement of cutters, the rotating body is rotated by 90° or 180° such that the opening of the rotating body faces an exchange opening near the side or back of the rotating body. The roller bit is then removed from the opening into the working space through the exchange opening, allowing replacement of the bit.

SUMMARY OF THE INVENTION

In the conventional literatures, however, the rotating body is disposed at the front of the cutter head (cutter spokes). Moreover, a sliding gap between the rotating body and a support member that supports the rotating body is exposed at the front of the cutter head. This may directly load a slop pressure to the sliding gap during drilling and cause fragments such as gravel to enter the sliding gap. Hence, a sealant provided in the sliding gap may be damaged or the rotations of the rotating body may be interrupted.

The present invention has been devised to solve the problem. An object of the present invention is to provide a bit exchange method and a bit exchange device for an excavator, which can improve sealing performance in a sliding gap so as to prevent the entry of muddy water.

An invention according to a first aspect is:

A bit exchange method for a shield tunneling machine in which a cutter head is supported at the front of a shield body so as to rotate around a shield axis, drilling bits are disposed on the front surface of the cutter head, and worn one of the drilling bits is exchanged from a working space provided in the cutter head,

the method including:

retracting the drilling bit from a drilling position where the drilling bit is protruded forward from the front plate of the cutter head through an opening, to a protruding/retracting hole formed on a holding cylinder in a bit housing case on the back side of the front plate; meanwhile, injecting a filler from the drilling bit into a retraction space containing the retracted drilling bit,

covering the opening surface of the holding cylinder by moving a gate plate so as to close an open/close space formed between the front plate and the opening surface of the holding cylinder in the bit housing case; and

discharging the filler injected between the gate plate and the drilling bit in the protruding/retracting hole with a pressure reduced to an atmospheric pressure, allowing the gate plate to come into contact with the edge of the protruding/retracting hole at the front of the holding cylinder by a pressure difference between a face collapse earth pressure for pressing the gate plate from the front surface of the gate plate and an atmospheric pressure on the back side of the gate plate, and closing the protruding/retracting hole by pressing a sealant disposed between the edge of the protruding/retracting hole and the gate plate.

An invention according to a second aspect, in the method of the first aspect,

the method further includes compressing the sealant by urging or retracting the gate plate backward with the pressure difference after closing the opening surface of the holding cylinder.

An invention according to a third aspect is:

a bit exchange device for a shield tunneling machine in which a cutter head is supported at the front of a shield body so as to rotate around a shield axis, drilling bits are disposed on the front surface of the cutter head, and worn one of the drilling bits is exchanged from a working space provided in the cutter head,

the bit exchange device including a bit housing case in the working space behind the back side of an opening formed on the front plate of the cutter head, the bit housing case covering the opening and including an insertion/removal opening where the drilling bit is insertable and removable on the back side of the bit housing case,

the bit housing case including:

a holding cylinder disposed with an open/close space between the opening of the front plate and the holding cylinder, the holding cylinder having a protruding/retracting hole for holding the drilling bit in a protruding or retracting manner along a protruding/retracting axis;

a bit fixture capable of fixing the drilling bit in the protruding/retracting hole, at a drilling position where the drilling bit protrudes forward from the opening of the front plate;

a gate plate movable in the open/close space so as to open and close the protruding/retracting hole;

a water sealant disposed between the gate plate and the edge of the protruding/retracting hole, on the front surface of the holding cylinder; and

a communicating hole formed on the drilling bit so as to supply a filler to the front of the drilling bit,

wherein the filler is injected into a retraction space at the front of the drilling bit from the communicating hole [a (filler) supply/discharge pipe is omitted] of the drilling bit while the drilling bit is retracted into the holding cylinder from the drilling position; the filler between the gate plate and the drilling bit is discharged from the communicating hole in the protruding/retracting hole after the protruding/retracting hole is closed by the gate plate; a space between the gate plate and the drilling bit communicates with the working space with a pressure reduced to an atmospheric pressure; and the gate plate is pressed to the front surface of the holding cylinder by a pressure difference between a face collapse earth pressure of the front side of the gate plate and an atmospheric pressure on the back side of the gate plate, pressing the water sealant so as to close the protruding/retracting hole.

An invention according to a fourth aspect, in the configuration of the third aspect,

the front surface of the holding cylinder and the gate plate are formed on a circular surface around an open/close axis perpendicular to the protruding/retracting axis behind the open/close space, and

the bit exchange device further including a bearing body provided on at least one of two ends disposed along an open/

close shaft direction, the bearing body rotationally supporting the gate plate via the open/close shaft, and

a movable support mechanism provided to movably guide the bearing body along the protruding/retracting axis direction.

An invention according to a fifth aspect, in the configuration of the fourth aspect,

the bit exchange device further includes one of an urging support mechanism and a driving support mechanism, the urging support mechanism urging the bearing body backward along the protruding/retracting axis, the driving support mechanism driving the bearing body along the protruding/retracting axis direction.

An invention according to a sixth aspect, in the configuration of any one of the third to fifth aspects,

the drilling bit is a roller bit including a disc cutter rotationally supported by a bit holder, and

the communicating hole formed on the bit holder is selectively connected to a mud discharge pipe for discharging mud drilled by the roller bit and a filler supply/discharge pipe capable of supplying and discharging the filler.

According to the invention of the first aspect, the filler is injected into the retraction space of the drilling bit, thereby preventing soil or mud from entering the bit housing case from the opening. The opening surface of the protruding/retracting hole is closed with the gate plate at the front of the holding cylinder, and then the filler injected between the gate plate and the drilling bit is discharged in the protruding/retracting hole with a pressure reduced to an atmospheric pressure. The gate plate is pressed to the edge at the front of the holding cylinder by a pressure difference between a face collapse earth pressure on the front surface of the gate plate and an atmospheric pressure at the back side of the gate plate, compressing the water sealant. This can effectively seal the opening surface of the holding cylinder. When the gate plate is opened or closed, the gate plate and the water sealant can be opened or closed in a noncontact manner or slightly in contact with each other. This can prevent damage on the water sealant, allowing the gate plate to be opened or closed with only a small amount of power.

According to the invention of the second aspect, the gate plate is pressed to the opening surface of the holding cylinder. Thus, even in the case of a small pressure difference between a face collapse earth pressure and an atmospheric pressure, the sealing performance can be maintained with reliability.

According to the invention of the third aspect, the filler is injected into the retraction space where the drilling bit is retracted. This can prevent soil and mud from entering the bit housing case from the opening. Moreover, the opening surface of the protruding/retracting hole is closed at the front of the holding cylinder by the gate plate, and then the filler injected between the gate plate and the drilling bit in the protruding/retracting hole is discharged from the communicating hole with a pressure reduced to an atmospheric pressure. Thus, the gate plate is pressed to the front of the holding cylinder by a pressure difference between a face collapse earth pressure loaded to the front surface of the gate plate and an atmospheric pressure loaded to the back side of the gate plate. This can compress the water sealant so as to effectively seal the opening surface of the holding cylinder. When the gate plate is opened or closed, the gate plate and the water sealant can be opened or closed in a noncontact manner or slightly in contact with each other. This can prevent damage on the water sealant, allowing the gate plate to be opened or closed with only a small amount of power.

According to the invention of the fourth aspect, the opening surface of the holding cylinder and the gate plate are formed on the circular surface, thereby pivotally opening and closing the gate plate about the open/close shaft with a small configuration. Moreover, the bearing body supporting the open/close shaft is movably supported by the movable support mechanism in the longitudinal direction along the protruding/retracting axis. This can effectively use a pressure difference so as to close the opening surface of the holding cylinder with the gate plate.

According to the invention of the fifth aspect, the gate plate can be pressed to the front of the holding cylinder by a pressure applied by the urging support mechanism or the driving support mechanism and a pressure difference between a face collapse earth pressure and an atmospheric pressure. This can more effectively compress the sealant to seal the opening of the holding cylinder. Even in the case of a small pressure difference between a face collapse earth pressure and an atmospheric pressure, the water sealant can be compressed by a pressure applied by the urging support mechanism or the driving support mechanism, thereby effectively sealing the front surface of the holding cylinder.

According to the invention of the sixth aspect, even if hard ground is drilled by the roller bit, the worn disc cutter can be easily exchanged from the working space. The mud discharge pipe is connected to the communicating hole formed in the bit holder of the roller bit, smoothly discharging drilled soil. The connection of the filler supply/discharge pipe can effectively supply the filler into the retraction space.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** illustrates a longitudinal section showing a main spoke as an embodiment of a bit exchange unit of a shield tunneling machine according to the present invention.

FIG. **2** is a cross-sectional view showing the main spoke as the bit exchange unit.

FIG. **3**A is a front view of the bit exchange unit.

FIG. **3**B is a rear view of the bit exchange unit.

FIG. **4** is an enlarged view of an A part of FIG. **1**.

FIG. **5** is an enlarged cross-sectional view showing a water sealant.

FIG. **6** is an explanatory drawing showing a movable support mechanism constituting a gate moving device.

FIG. **7** is an explanatory drawing showing an urging support mechanism constituting the gate moving device.

FIG. **8**A is a side cross-sectional view showing a screw jack structure as an example of a driving support mechanism constituting the gate moving device.

FIG. **8**B is a side view showing a cylinder structure as an example of the driving support mechanism constituting the gate moving device.

FIG. **8**C is a side view showing an eccentric axis structure as an example of the driving support mechanism constituting the gate moving device.

FIG. **9** is a side cross-sectional view for explaining a state of a retracted bit in the step of exchanging the bit.

FIG. **10** is a side cross-sectional view for explaining a closed state of a holding cylinder in the step of exchanging the bit.

FIG. **11** is an overall front view of a shield tunneling machine.

FIG. **12** shows an overall longitudinal section of the shield tunneling machine.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

An embodiment of a bit exchange device for a shield tunneling machine according to the present invention will be described below with reference to the accompanying drawings.

(Shield tunneling machine) As shown in FIG. **12**, a shield tunneling machine includes a pressure bulkhead **12** provided at the front of a cylindrical shield body **11**, and a pressure chamber **19**A provided at the front of the pressure bulkhead **12** so as to keep a face collapse earth pressure. The pressure bulkhead **12** has a slewing ring body **14** supported via a slewing bearing **13** so as to rotate about a shield axis O. A circular cutter head **16** covering the front surface of the pressure chamber **19**A is supported by a plurality of support legs **15** protruding to the front from the slewing ring body **14**. An atmospheric space **19**B behind the pressure bulkhead **12** contains a cutter drive unit **17** that rotates the cutter head **16**. The cutter drive unit **17** includes a ring gear **17***a* provided on the back of the slewing ring body **14**, a plurality of drive pinions **17***b* engaged with the ring gear **17***a*, and a rotating unit (hydraulic or electric motor) **17***c* which rotates each of the drive pinions **17***b*. Furthermore, a soil-removing screw conveyor **18** penetrates the pressure bulkhead **12**. The soil-removing screw conveyor **18** discharges soil drilled by the cutter head **16**, from the pressure chamber **19**A to the atmospheric space **19**B with a kept face collapse earth pressure.

(Cutter head) As shown in FIG. **11**, the cutter head **16** includes a plurality of main spokes **21** radially extending from a center member **20** disposed on the shield axis O, a plurality of sub spokes **22** radially extending between the main spokes **21**, and an intermediate ring **23** and an outer ring **24** that are circularly disposed around the shield axis O so as to connect the main spokes **21** and the sub spokes **22**. Soil inlet openings **25** are formed between the members **21** to **24**.

Furthermore, a plurality of bit exchange units (bit exchange device) **30** and fixed cutter bits **32** according to the present invention are alternately disposed at the front of the main spoke **21**. The bit exchange units **30** each have a roller bit (drilling bit) **31**. Moreover, a plurality of fixed bits **26** are provided on the center member **20**, at the front and sides of the sub spokes **22**, and at the front of the main spoke **21**.

As shown in FIG. **11**, a manhole **27** allowing the passage of workers is provided at the rear of the center member **20**. The manhole **27** penetrates the pressure bulkhead **12** so as to allow the passage of workers from the atmospheric space **19**B. Furthermore, a working space **28** at atmospheric pressure is formed behind the main spokes **21** so as to allow a worker to exchange the bits. The manhole **27** communicates with the working space **28** such that a worker can enter and return from the working space **28** from the manhole **27**. During drilling, the worn roller bits **31** can be exchanged from the working space **28**.

(Bit exchange unit) As shown in FIGS. **1** to **3**A and **3**B, the bit exchange unit **30** has an opening **34** formed on a unit front plate (front plate) **33** disposed in the notch of a front plate **21**F of the main spoke **21**. The roller bit **31** at a drilling position is protruded from the opening **34**. On the back side of the unit front plate **33**, a bit housing case **35** is attached from the periphery of the opening **34** near the working space **28**. The bit housing case **35** is shaped like a box having a left side plate **35**L, a right side plate **35**R, a top plate **35**U, a bottom plate **35**D, and a back side plate **35**B that are fixed on the unit front plate **33**. The plates are closed except for the front-side opening **34** and a rear-side insertion/removal opening **36**, which will be described later. The back side plate **35**B is divided near the bottom of the main spoke **21** into a lower half serving as a fixed portion **35**Ba on the unit front plate **33** and an upper half serving as a separated portion **35**Bb removable from the fixed portion **35**Ba. The insertion/removal opening **36** is formed between the fixed portion **35**Ba and the separated portion **35**Bb such that the roller bit **31** can be inserted and removed from the insertion/removal opening **36**.

In the bit housing case **35**, a holding cylinder **37** is installed behind the opening **34** of the unit front plate **33**. The holding cylinder **37** has a protruding/retracting hole **37***a* formed along, for example, a protruding/retracting axis Oa parallel to the shield axis O. The roller bit **31** is supported in the protruding/retracting hole **37***a* so as to protrude and retract in the longitudinal direction. The bit housing case **35** has an open/close space **38**, in which a gate plate **51** is movable, between the holding cylinder **37** and the unit front plate **33**. Furthermore, a gate housing space **39** capable of housing the gate plate **51** is formed on the holding cylinder **37**. The holding cylinder **37** further includes an opening surface **37***b* where the protruding/retracting hole **37***a* is opened and closed by the gate plate **51**, the opening surface **37***b* facing the open/close space **38** at the front of the holding cylinder **37**. The opening surface **37***b* and the gate plate **51** are formed on a circular surface about an open/close axis Ob of the tangential direction of the cutter head **16** that is perpendicular to the protruding/retracting axis Oa behind the holding cylinder **37**. The roller bit **31** is formed in a bit holder **42** that is shaped like a tube substantially oval and rectangular in cross section. A mud discharge space **41** is formed in the longitudinal direction at the front of the bit holder **42**. Two disc cutters **44** are rotationally supported at the front of the mud discharge space **41** via a spindle **43** provided along the breadth of the disc cutter **44**.

Furthermore, bit sealants **45**A are attached to the inner surface of the opening **34** on the unit front plate **33** with attachment grooves. Additionally, bit sealants **45**B are attached to the outer surface of the intermediate part of the bit holder **42** with attachment grooves.

(Bit fixtures) As shown in FIGS. **1** and **4**, a plurality of bit fixtures **46** are provided in the rear of the bit housing case **35**. The bit fixtures **46** can fix the bit holder **42** at a drilling position and can release the bit holder **42** at the time of replacement. On the bit housing case **35** and the bit holder **42**, the bit fixture **46** has a block fitting portion **48** and a fixed member **47** that is fit into the block fitting portion **48**. The block fitting portion **48** has a square groove formed that is longitudinally extended with an inclined end face **48***a* and an inclined support face **48***b* at an angle of substantially 90°, behind and in the upper and lower portion of the long side of the bit housing case **35**. Moreover, an inclined receiving surface **48***c* is formed on the back side of the holding cylinder **37** so as to form an angle of substantially 90° with respect to the inclined end face **48***a*. The fixed member **47** includes a shaft-shaped nut (barrel nut) **47***a* that is attached into a support hole **35***a* formed on the holding cylinder **37** in the long side direction of the bit housing case **35**, a fixed bolt **47***b* that can be attached, removed, and fastened in the female threaded hole of the shaft-shaped nut **47***a*, and an edge block **47***c* shaped like a rectangular solid fit into the block fitting portion **48**. The edge block **47***c* has a through hole **47***d* where the fixed bolt **47***b* is fit. This fits the edge block **47***c* into the block fitting portion **48**. The fixed bolt **47***b* is attached and fastened into the female threaded hole of the shaft-shaped nut **47***a* from the through hole **47***d* so as to press the inclined end face **48***a* and the inclined receiving surface **48***c* with the edge block **47***c*. This can firmly fix the disc cutters **44** to the main spoke **21** via the bit holder **42** by means of the fixed member **47**. At this point, the drilling reaction force of the roller bit **31** is transmitted from the inclined receiving surface **48***c* to the inclined support face **48***b* and is supported by the bit housing case **35**.

(Gate open/close device) The bit housing case **35** contains a gate open/close device **50** including the gate plate **51** that can open and close the opening surface **37***b* of the holding cylinder **37**. The gate open/close device **50** includes the gate

plate **51**, open/close shafts **52** that can open and close the gate plate **51** by means of an electric, hydraulic, or manual rotating tool, and a gate sealing member that can close the protruding/retracting hole **37***a* of the holding cylinder **37** with the gate plate **51**.

A fan-shaped connecting plate **53** that extends to the open/close axis Ob from left and right circular sector sides is attached to the gate plate **51**. The fixed end of the connecting plate **53** is fixed to the open/close shafts **52** that are rotationally supported to penetrate the left and right side plates **35**R and **35**L. Thus, the open/close shafts **52** are rotated by the rotating tool so as to pivot the gate plate **51** between an opening position in the gate housing space **39** and a closing position in the open/close space **38**, thereby opening and closing the protruding/retracting hole **37***a* of the opening surface **37***b*.

A water sealant **40** for sealing a gap between the opening surface **37***b* and the gate plate **51** at the closing position is provided so as to extend over the inner surface of the gate plate **51**. As shown in FIG. **5**, the water sealant **40** is, for example, a special O ring substantially pentagonal in cross section. The O ring has attachment portions **40***a* that are rectangular in cross section and are fit into housing grooves and sliding contact portions **40***b* that are angular in cross section and protrude from the attachment portions **40***a*. As a matter course, the water sealant **40** may be provided along the edge of the protruding/retracting hole **37***a* of the opening surface **37***b*.

Regarding the water sealant **40** and the bit sealants **45**A and **45**B, the water sealant **40** and the bit sealant **45**B can be exchanged from the working space **28** under atmospheric pressures. Specifically, if the water sealant **40** is replaced with another, the separated portion **35**Bb of the back side plate **35**B is removed, and then the open/close shafts **52** are separated so as to remove the gate plate **51** into the working space **28**. This allows the replacement of the broken water sealant **40**. If the bit sealant **45**B is replaced with another, the broken bit sealant **45**B can be replaced when the bit holder **42** is drawn to replace the roller bit **31**. Hence, even if the water sealant **40** or the bit sealant **45**B is broken during drilling, the sealant can be replaced from the working space **28** while cutting off water. This improves the reliability of the bit exchange unit **30**.

A mud discharge pipe **55** for discharging soil drilled by the disc cutters **44** is connected to the bit holder **42** of the roller bit **31**. The bit holder **42** has a communicating hole **57**A that communicates with the mud discharge space **41**. The mud discharge pipe **55** is connected to the back side of the communicating hole **57**A. The mud discharge pipe **55** extends along the protruding/retracting axis Oa in the working space **28**, penetrates a back side plate **21**R of the main spoke **21**, and is opened on the pressure chamber **19**A. The mud discharge pipe **55** includes a first mud discharge valve **56**A connected to the communicating hole **57**A, a separating flange for the valve **56**A, a second mud discharge valve **56**B connected to a penetrating portion in the back side plate **21**R, a separating flange for the valve **56**B, and a mud discharge pipe body **55***a* separably connected between the two separating flanges. Thus, the two separating flanges can be separated from each other to remove the mud discharge pipe body **55***a* during the replacement of the bit.

Moreover, two communicating holes **57**B and **57**C communicating with the mud discharge space **41** are opened on the back side of the bit holder **42**. Open/close valves **58**A and **58**B are attached to the communicating holes **57**B and **57**C, respectively. Furthermore, a filler supply pipe (filler supply/discharge pipe) **59**A, a filler discharge pipe (filler supply/discharge pipe) **59**B, a wash water supply pipe **59**C, and a wash water discharge pipe **59**D (may be shared with the filler discharge pipe **59**B) are selectively connected to the open/close valves **58**A and **58**B so as to supply and discharge a filler and wash water.

(Gate sealing member) The gate sealing member applies a pressure to seal the gate plate **51** by using a pressure difference between a face collapse earth pressure (drilling ground pressure) that presses the gate plate **51** from the front and an atmospheric pressure (a barometric pressure in the working space **28**). Basically, as will be described later in A), only a movable support mechanism **61** is necessary that uses only a pressure difference between a face collapse earth pressure and an atmospheric pressure. In preparation for a reduction in sealing performance because of a small pressure difference between a face collapse earth pressure and an atmospheric pressure, a gate seal reinforcing member is provided to compress the water sealant **40** by retracting the gate plate **51** via the open/close shafts **52** along the protruding/retracting axis Oa direction. The gate seal reinforcing member is, for example, an urging support mechanism **62** that urges the open/close shafts **52** backward as will be described later in B), and first to third driving support mechanisms **63**A to **63**C that drive the open/close shafts **52** backward with a mechanical driving force as will be described later in C) to E). The gate seal reinforcing member is selected from B) to E), which will be described later.

Referring to FIGS. **6** to **8**C, the movable support mechanism **61**, the urging support mechanism **62**, and the first to third driving support mechanisms **63**A to **63**C will be described below. The same members are indicated by the same reference numerals and the explanation thereof is omitted.

A) As shown in FIG. **6**, the movable support mechanism **61** includes a bearing body **64** that rotationally supports a pair of the left and right open/close shafts **52**, and a bearing guide frame **65** that movably supports the bearing body **64** in a predetermined range along the protruding/retracting axis Oa direction. Guide rails **65***a* are provided along the upper and lower sides of the guide space of the guide frame **65**. The bearing body **64** is guided so as to longitudinally move along the upper and lower guide rails **65***a*.

Thus, during replacement, the roller bit **31** is retracted to the protruding/retracting hole **37***a*; meanwhile, a filler is injected into the retraction space (including the open/close space **38** and the gate housing space **39**) of the roller bit **31** from the filler supply pipe **59**A through the communicating hole **57**B. The open/close shafts **52** are then rotated using a manual or rotating tool so as to move the gate plate **51** from the opening position to the closing position, thereby closing the protruding/retracting hole **37***a* of the holding cylinder **37**. After that, the filler injected between the gate plate **51** and the roller bit **31** is discharged into the filler discharge pipe **59**B through the communicating hole **57**C and then is fed into the atmospheric pressure side of the working space **28**. Hence, the front side of the gate plate **51** having a filler residue receives a high pressure because of a face collapse earth pressure, whereas the communicating hole **57**B behind the gate plate **51** after the discharge of the filler communicates with the working space **28** under an atmospheric pressure. Thus, the gate plate **51** is pressed by a pressure difference between a face collapse earth pressure and an atmospheric pressure, the open/close shafts **52** are displaced backward via the bearing body **64** and the bearing guide frame **65** along the protruding/retracting axis Oa direction, and the gate plate **51** is pressed to the opening surface **37***b*. This compresses the water sealant **40** so as to seal the protruding/retracting hole **37***a* of the holding cylinder **37**.

B) As shown in FIG. **7**, the urging support mechanism **62** includes a compression coil spring **67**A or extension coil springs **67**B which urge the bearing body **64** of the movable support mechanism **61** backward along the protruding/retracting axis Oa. Moreover, in order to prevent the application of a biasing force of the coil springs **67**A and **67**B to the bearing body **64** when the gate plate **51** is opened or closed, the bearing guide frame **65** includes a screw-type open/close shaft fixture **68** with a threaded shaft **68***a* that regulates retraction of the bearing body **64**.

Thus, the open/close shaft fixture **68** holds the bearing body **64** at a position where the water sealant **40** of the gate plate **51** does not come into contact with the opening surface **37***b* of the holding cylinder **37**. The gate plate **51** is then moved to the closing position by the rotating tool so as to close the protruding/retracting hole **37***a* of the holding cylinder **37**. After that, the filler injected between the gate plate **51** and the roller bit **31** is discharged through the filler discharge pipe **59**B, the inside of the protruding/retracting hole **37***a* behind the gate plate **51** communicates with the working space **28** so as to be decompressed to an atmospheric pressure after the discharge of the filler. At that time or thereafter, the open/close shaft fixture **68** is retracted and released. Thus, the gate plate **51** is pressed to the opening surface **37***b* by a pressure difference between a face collapse earth pressure and an atmospheric pressure and the biasing force of the compression coil spring **67**A (or the extension coil spring **67**B). The water sealant **40** is then compressed to effectively seal the protruding/retracting hole **37***a* of the holding cylinder **37**.

C) As shown in FIG. **8**A, the first driving support mechanism **63**A includes a manual (may be electric or hydraulic) jack device **69** that drives the gate plate **51** to the bearing body **64** of the movable support mechanism **61** in a predetermined range along the protruding/retracting axis Oa direction. Thus, the gate plate **51** is moved to the closing position and then the bearing body **64** is moved backward by the jack device **69** so as to press the gate plate **51** to the opening surface **37***b*. At the same time, the filler injected between the gate plate **51** and the roller bit **31** is discharged through the filler discharge pipe **59**B, reducing a pressure in the protruding/retracting hole **37***a* behind the gate plate **51** to an atmospheric pressure. Hence, the gate plate **51** at the closing position is pressed to the opening surface **37***b* by a pressure applied from the gate plate **51** by the jack device **69** and a pressure difference between a face collapse earth pressure and an atmospheric pressure, allowing the water sealant **40** to effectively seal the protruding/retracting hole **37***a* of the holding cylinder **37**.

D) As shown in FIG. **8**B, the second driving support mechanism **63**B includes a hydraulic enclosing cylinder **70** connected to the bearing body **64** of the movable support mechanism **61**. The enclosing cylinder **70** drives the gate plate **51** in a predetermined range along the protruding/retracting axis Oa direction. This presses the gate plate **51** at the closing position to the opening surface **37***b* by using a pressure difference between a face collapse earth pressure applied by the movable support mechanism **61** and an atmospheric pressure and a pressure applied by the enclosing cylinder **70**, compressing the water sealant **40** so as to effectively seal the protruding/retracting hole **37***a* of the holding cylinder **37**.

E) As shown in FIG. **8**C, the third driving support mechanism **63**C includes an eccentric displacing device **71** that can move the gate plate **51** in a predetermined range along the protruding/retracting axis Oa direction.

The eccentric displacing device **71** causes an external bearing body **72** attached to the bit housing case **35** to rotationally support an external rotating body **73**. The bearing body **64** for rotationally supporting the open/close shafts **52** is provided at a position decentered from a rotation axis Oc of the external rotating body **73** by an eccentricity Δd. For a rotation of the external rotating body **73** in a predetermined range, for example, a manual bevel gear device **74** is provided. Thus, the gate plate **51** is moved from the opening position via the open/close shafts **52** to the closing position for covering the opening surface **37***b*, and then the bevel gear device **74** is driven to rotate the external rotating body **73** in an arrow direction, moving the bearing body **64** backward by a predetermined distance Lb. This can press the gate plate **51** to the opening surface **37***b*. Moreover, the filler injected between the gate plate **51** and the roller bit **31** is discharged from the filler discharge pipe **59**B to communicate with the working space **28**, reducing a pressure in the communicating hole **57**B to an atmospheric pressure after the discharge of the filler. Hence, the gate plate **51** at the closing position is pressed to the opening surface **37***b* by a pressure applied from the gate plate **51** by the eccentric displacing device **71** and a pressure difference between a face collapse earth pressure and an atmospheric pressure, allowing the water sealant **40** to effectively seal the protruding/retracting hole **37***a* of the holding cylinder **37**.

(Exchanging operation) An exchanging operation of the bit exchange unit **30** including the manual jack device **69** in the urging support mechanism **62** will be described below.

1) The rotation of the cutter head **16** is stopped, and then a worker enters the working space **28** and moves to the back side of the worn roller bit **31**. The filler supply pipe **59**A and the filler discharge pipe **59**B are connected to the open/close valves **58**A and **58**B, respectively. Subsequently, the first and second mud discharge valves **56**A and **56**B of the mud discharge pipe **55** are closed, and then the mud discharge pipe body **55***a* is removed. After that, the bit fixtures **46** are removed to release the roller bit **31**, and then a push/pull tool (not shown) such as a jack is attached between the bit holder **42** and the back side plate **21**R of the main spoke **21** so as to draw the roller bit **31**.

2) As shown in FIG. **9**, the open/close valve **58**A is opened to inject a filler M from the filler supply pipe **59**A; meanwhile, the push/pull tool draws the roller bit **31** to the protruding/retracting hole **37***a* along the protruding/retracting axis Oa. This supplies the filler into a space where the roller bit **31** at the front has retracted from the mud discharge space **41**. This prevents a flow of soil entering from the opening **34**. When the bit holder **42** is drawn into the protruding/retracting hole **37***a*, the filler M is injected into the open/close space **38** and the gate housing space **39** from the protruding/retracting hole **37***a*.

3) When the disc cutters **44** are completely drawn into the gate housing space **39**, the open/close valve **58**A is closed to stop the supply of the filler M. The gate open/close device **50** is then started to move the gate plate **51** from the opening position to the closing position of the open/close space **38**, thereby closing the protruding/retracting hole **37***a* of the holding cylinder **37**. After that, the jack device **69** is operated to press the gate plate **51** to the opening surface **37***b*; meanwhile, as shown in FIG. **10**, the open/close valve **58**B is opened to discharge the filler, which has been injected between the gate plate **51** and the roller bit **31**, into the working space **28** from the filler discharge pipe **59**B, causing the protruding/retracting hole **37***a* to communicate with the working space **28** under an atmospheric pressure. Thus, the gate plate **51** at the closing position is pressed to the opening surface **37***b* by a pressure applied from the gate plate **51** by the jack device **69** and a pressure difference between a face collapse earth pressure and an atmospheric pressure. This com-

presses the water sealant **40** so as to effectively seal the protruding/retracting hole **37***a* of the holding cylinder **37**.

4) The filler supply pipe **59**A and the filler discharge pipe **59**B are removed from the bit holder **42**. The absence of a water leak from the opening surface **37***b* to the protruding/retracting hole **37***a* is confirmed, and then the bit holder **42** is drawn by the push/pull tool into the working space **28** from the protruding/retracting hole **37***a* through the insertion/removal opening **36**.

5) The bit holder **42** provided with a new roller bit **31** is inserted into the protruding/retracting hole **37***a* of the holding cylinder **37** and is pressed by the push/pull tool, and then the wash water supply pipe **59**C and the wash water discharge pipe **59**D are connected to the open/close valves **58**A and **58**B of the bit holder **42**. The gate open/close device **50** is then started to move the gate plate **51** from the closing position to the opening position, thereby opening the protruding/retracting hole **37***a* of the holding cylinder **37**. After that, the bit holder **42** is pressed to the front in the protruding/retracting hole **37***a* by the push/pull tool; meanwhile, the open/close valves **58**A and **58**B are opened to supply wash water to the front of the bit holder **42** from the wash water supply pipe **59**C and discharge wash water containing the filler from the wash water discharge pipe **59**D. Furthermore, the roller bit **31** is protruded to a use position from the opening **34** of the unit front plate **33** and then is locked by the bit fixtures **46**.

(Effect of the embodiment) According to the embodiment, the roller bit **31** is retracted from a drilling position; meanwhile, the filler is injected into the mud discharge space **41** of the roller bit **31** from the filler supply pipe **59**A and into the open/close space **38**, the opening **34**, and the retraction space of the roller bit **31** in the ground from the protruding/retracting hole **37***a* of the holding cylinder **37**. This can prevent soil or mud from entering the bit housing case **35** from the opening **34**. Moreover, the gate plate **51** closes the opening surface **37***b* of the protruding/retracting hole **37***a* of the holding cylinder **37**, and then the filler injected into the protruding/retracting hole **37***a* between the gate plate **51** and the roller bit **31** in the holding cylinder **37** is discharged from the filler discharge pipe **59**B, allowing the protruding/retracting hole **37***a* to communicate with the working space **28** with a pressure reduced to an atmospheric pressure. Thus, the gate plate **51** is pressed to the opening surface **37***b* of the holding cylinder **37** by a pressure difference between a face collapse earth pressure at the front of the gate plate **51** and an atmospheric pressure at the rear of the gate plate **51**. This compresses the water sealant **40** so as to effectively seal the protruding/retracting hole **37***a* at the front of the holding cylinder **37**. Furthermore, the gate plate **51** can be opened or closed in a noncontact manner or slightly in contact with the front side of the holding cylinder **37**. This can prevent damage on the water sealant **40** provided on the inner surface of the gate plate **51**. Moreover, the gate plate **51** can be opened or closed with only a small amount of power.

The front surface of the holding cylinder **37** and the gate plate **51** are formed on the circular surface around the open/close shafts **52**, thereby pivotally opening and closing the gate plate **51** about the open/close shafts **52**. This configuration makes it possible to form the gate housing space **39** in the upper and lower parts and left and right sides of the holding cylinder **37** in the bit housing case **35**, achieving the bit housing case **35** with a small configuration.

Moreover, the bearing body **64** supporting the open/close shafts **52** is supported by the movable support mechanism **61** so as to longitudinally move along the protruding/retracting axis Oa. Only with this configuration, the gate plate **51** can be effectively brought into contact with the opening surface **37***b* of the holding cylinder **37** by a pressure difference between a face collapse earth pressure and an atmospheric pressure, thereby closing the protruding/retracting hole **37***a* of the holding cylinder **37**. When the gate plate **51** is opened or closed, the water sealant **40** does not strongly slide in contact with the gate plate **51**. This can minimize damage to the water sealant **40** when the gate plate **51** is opened or closed.

Moreover, the urging support mechanism **62** fixes the open/close shafts **52** with the open/close shaft fixture **68** when the gate plate **51** is opened or closed. The fixed open/close shafts **52** are released with the closed gate plate **51**, allowing the coil springs **67**A and **67**B to press the gate plate **51** to the opening surface **37***b*. The gate plate **51** can be pressed to the opening surface **37***b* of the holding cylinder **37** by the biasing force of the coil springs **67**A and **67**B and a pressure difference between a face collapse earth pressure and an atmospheric pressure. Thus, even if the pressure difference is small, the water sealant **40** can be effectively compressed so as to effectively seal the protruding/retracting hole **37***a* of the holding cylinder **37**.

Moreover, according to the first to third driving support mechanisms **63**A to **63**C, the gate plate **51** is pressed to the opening surface **37***b* of the holding cylinder **37** by a pressure for mechanically pressing the gate plate **51** to the opening surface **37***b* of the holding cylinder **37** and a pressure difference between a face collapse earth pressure and an atmospheric pressure, thereby effectively sealing the protruding/retracting hole **37***a* of the holding cylinder **37**. Thus, even if the pressure difference is small, the water sealant **40** can be effectively compressed so as to effectively seal the protruding/retracting hole **37***a* of the holding cylinder **37**.

Since the roller bit **31** is used as a drilling bit, the worn roller bit **31** can be easily exchanged from the inside even during drilling on the considerably worn hard ground. Moreover, the filler supply pipe **59**A and the filler discharge pipe **59**B can be connected to the bit holder **42** that holds the disc cutters **44**, by using the mud discharge space **41**. This configuration makes it possible to effectively supply and discharge the filler and wash water and smoothly supply and discharge the filler to the retraction space of the roller bit **31**. Furthermore, the filler can be easily washed with wash water.

The roller bit **31** in the present embodiment may be replaced with a fixed cutter bit.

The invention claimed is:

1. A bit exchange method for a shield tunneling machine in which a cutter head is supported at a front of a shield body so as to rotate around a shield axis, drilling bits are disposed on a front surface of the cutter head, and worn one of the drilling bits is exchanged from a working space provided in the cutter head,

the method comprising:

retracting the drilling bit from a drilling position where the drilling bit is protruded forward from a front plate of the cutter head through an opening, to a protruding/retracting hole formed on a holding cylinder in a bit housing case on a back side of the front plate; meanwhile, injecting a filler from the drilling bit into a retraction space containing the retracted drilling bit,

covering an opening surface of the holding cylinder by moving a gate plate so as to close an open/close space formed between the front plate and the opening surface of the holding cylinder in the bit housing case; and

discharging the filler injected between the gate plate and the drilling bit in the protruding/retracting hole with a pressure reduced to an atmospheric pressure, allowing the gate plate to come into contact with an edge of the protruding/retracting hole at a front of the holding cyl-

inder by a pressure difference between a face collapse earth pressure for pressing the gate plate from a front surface of the gate plate and an atmospheric pressure on a back side of the gate plate, and closing the protruding/retracting hole by pressing a sealant disposed between the edge of the protruding/retracting hole and the gate plate.

2. The bit exchange method for a shield tunneling machine according to claim **1**, further comprising compressing the sealant by urging or retracting the gate plate backward with the pressure difference after closing the opening surface of the holding cylinder.

3. A bit exchange device for a shield tunneling machine in which a cutter head is supported at a front of a shield body so as to rotate around a shield axis, drilling bits are disposed on a front surface of the cutter head, and worn one of the drilling bits is exchanged from a working space provided in the cutter head,

the bit exchange device comprising a bit housing case in the working space behind a back side of an opening formed on a front plate of the cutter head, the bit housing case covering the opening and including an insertion/removal opening where the drilling bit is insertable and removable on a back side of the bit housing case,

the bit housing case comprising:

a holding cylinder disposed with an open/close space between the opening of the front plate and the holding cylinder, the holding cylinder having a protruding/retracting hole for holding the drilling bit in a protruding or retracting manner along a protruding/retracting axis;

a bit fixture capable of fixing the drilling bit in the protruding/retracting hole, at a drilling position where the drilling bit protrudes forward from the opening of the front plate;

a gate plate movable in the open/close space so as to open and close the protruding/retracting hole;

a water sealant disposed between the gate plate and an edge of the protruding/retracting hole, on a front surface of the holding cylinder; and

a communicating hole formed on the drilling bit so as to supply a filler to a front of the drilling bit,

wherein the filler is injected into a retraction space at the front of the drilling bit from the communicating hole [a (filler) supply/discharge pipe is omitted] of the drilling bit while the drilling bit is retracted into the holding cylinder from the drilling position; the filler between the gate plate and the drilling bit is discharged from the communicating hole in the protruding/retracting hole after the protruding/retracting hole is closed by the gate plate; a space between the gate plate and the drilling bit communicates with the working space with a pressure reduced to an atmospheric pressure; and the gate plate is pressed to the front surface of the holding cylinder by a pressure difference between a face collapse earth pressure of a front side of the gate plate and an atmospheric pressure on a back side of the gate plate, pressing the water sealant so as to close the protruding/retracting hole.

4. The bit exchange device for a shield tunneling machine according to claim **3**, wherein the front surface of the holding cylinder and the gate plate are formed on a circular surface around an open/close axis perpendicular to the protruding/retracting axis behind the open/close space, and

the bit exchange device further comprising a bearing body provided on at least one of two ends disposed along an open/close shaft direction, the bearing body rotationally supporting the gate plate via an open/close shaft, and

a movable support mechanism provided to movably guide the bearing body along the protruding/retracting axis direction.

5. The bit exchange device for a shield tunneling machine according to claim **4**, further comprising one of an urging support mechanism and a driving support mechanism, the urging support mechanism urging the bearing body backward along the protruding/retracting axis, the driving support mechanism driving the bearing body along the protruding/retracting axis direction.

6. The bit exchange device for a shield tunneling machine according to any one of claims **3** to **5**, wherein the drilling bit is a roller bit including a disc cutter rotationally supported by a bit holder, and

the communicating hole formed on the bit holder is selectively connected to a mud discharge pipe for discharging mud drilled by the roller bit and a filler supply/discharge pipe capable of supplying and discharging the filler.

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